Wavelet multi-resolution analysis of TPRD and RNSIC input current

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Abstract: - It is well-known the fact that the frequency-domain approach obtained by Fourier transforms (FT) can provide amplitude-frequency spectrum while losing time-related information. In non-stationary regime, some of power electronics equipment connected to grid requires time related information, which cannot be provided by FT. Using discrete wavelet transform (DWT), we can preserve the information concerning time and frequency. In this paper, an wavelet analysis of input current of three-phase rectifier with diode (TPRD) and rectifier with near sinusoidal current (RNSIC) are presented. The experimental results are imported in MATLAB for multi-resolution analysis (MRA). Results of MRA confirm the reduction of RNSIC input current discontinuities, the waveform coming closer to sinusoidal form.

Key-Words: - Wavelet, multi-resolution analysis, rectifier, TPRD, RNSIC, AC/ DC converters.

1 Introduction

The three-phase rectifiers with diode (TPRD) are conventional three-phase rectifiers with dc-side C filters and are commonly used as interface between power systems and power electronic equipments for their simplicity and reliability [1]-[4]. The big problem of TPRD derives from the nonlinear characteristic of diodes. Consequently, the input current drawings from the power system feature large amounts of harmonics. The currents are severely distorted, the real power factor ($p_{f\ real}$) is low [32], [35], the total harmonics distortions (THD) of input current exceed the limits imposed by IEEE 519/1992 and IEC 61000-3-4 international standards, in SUA, and Europe respectively [28], [29], [31]. This requires a series of restrictions regarding the level of current harmonics in Point of Common Coupling (PCC) [19]-[20].

Most field papers suggest a variety of alternatives for harmonics filtering, which can be grouped in two categories: classical passive filters (CPFs) and active power filter (APF).

The first technique to reduce input current harmonics consists in the use of classical LC series circuits tuned in harmonics frequency [17]-[18].

The second technique requires several methods, among which injection of third-order current harmonics is the most widely spread [6]-[8].

In recent years, Prof. D. Alexa has proposed some novel rectifier topologies with passive filters (PFs), called rectifiers with near sinusoidal currents (RNSICs) [9]-[16].

A RNSIC converter is obtained by adding input inductors to classical three-phase rectifier with diode, and commutation capacitors connected with the diodes [9]-[16], [24]-[27]. This rectifier improves the input current, decreases the total harmonics distortions and corrects the power factor [21]-[23], [30].

The active power filters (APFs) remain slightly inferior to RNSICs, with respect to cost, efficiency and reliability [33], [36]-[37].

Despite the fact that it has been used for more than 150 years, Fourier transform is characterized by certain limitations regarding non-stationary regime and discontinuous signals. On the other hand, the calculus amount is important.

The wavelet transform is a transformation that preserves the information concerning time and frequency, which accounts for its use in discontinuous signal analysis [5], [34].

Our paper is organized in five sections: the second section presents the Fourier harmonic analysis of three-phase input current followed by a section of wavelet analysis of the same current. Section 4 presents the Fourier and wavelet harmonic analysis of RNSIC drawn current.

Experimental results of TPRD and RNSIC input current have been multi-resolution analyzed and they confirm the current distortion reduction, in case of RNSIC converter.

2 Fourier harmonics analysis of three-phase rectifiers input current

In figure 1, the three-phase rectifiers with diodes (TPRDs) are presented.

There exist two topologies: with inductors on a.c. side for each phase, and with an inductor on d.c. side. Next, we shall analyze the first topology, since this is the closest to RNSIC. The value of the three input inductors is 7.5 mH and they are series grid connected.

The harmonics analysis of the input currents (figure 2) indicates the important presence of superior harmonics. In these conditions, the ratio I_n/I_1 and THD (78.4%) are bigger than the international standard limits (5%).

The increase of inductor values does not solve the above presented problems.

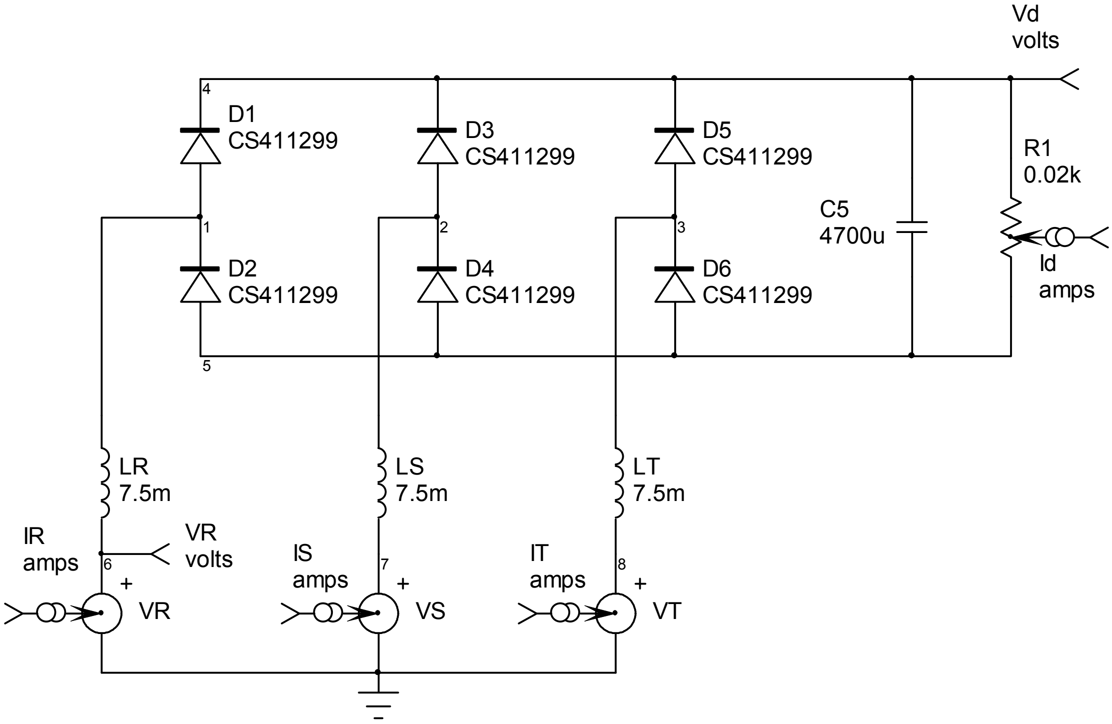
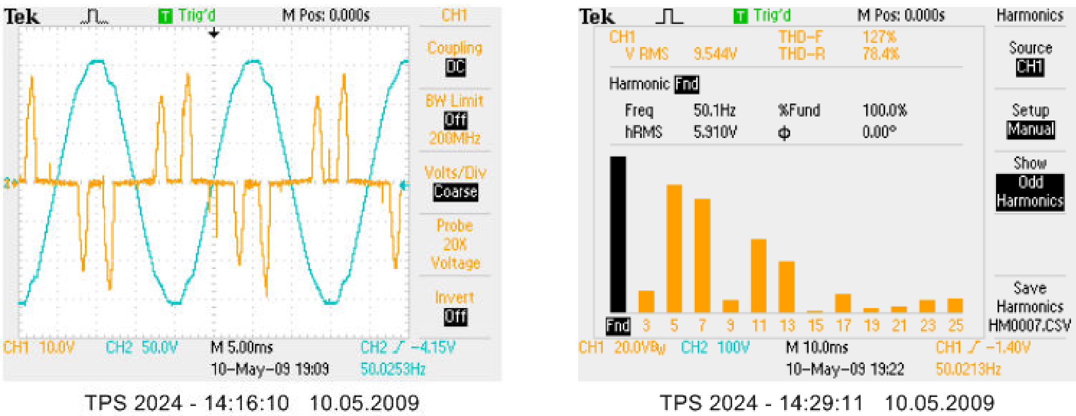


Fig. 1. Three-phase rectifier with diode (TPRD).



a) b)

Fig. 2. a) Phase current (I_R) and phase voltage (U_R); b) Fourier analysis of drawn phase current [22].

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3 Wavelet analysis of three-phase rectifiers input current

Wavelet analysis is the process of transforming the waveforms defined in the time domain into time-frequency domain. The transformation uses the wavelet functions, called mother wavelet.

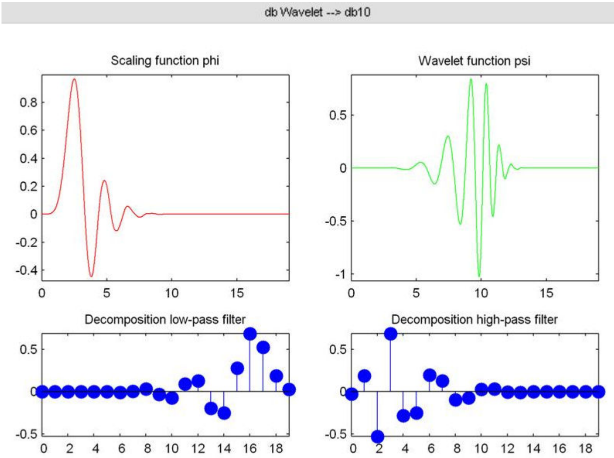

Fig. 4 The daughter and mother Daubechies 10 wavelet functions.

The continuous wavelet transform (CWT) requires to calculate the continuous wavelet coefficients (C) at every scale (frequency) and position (time):

$$C(\nu,\tau)=\frac{1}{\sqrt{\nu}}\int S(t)\cdot\psi\left(\frac{t-\tau}{\nu}\right)dt \qquad (1)$$

A considerable benefit of wavelet analysis consists in its ability to perform the *local analysis* – referring to the analysis of a smaller area of a wider signal.

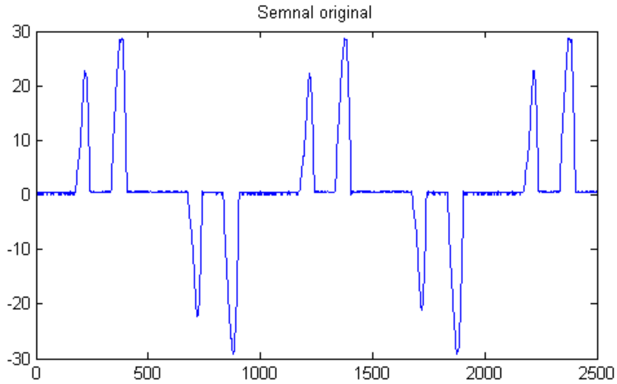

Fig. 6. The original TPRD input current waveform (2500 samples).

Starting from the original signal form to be analyzed, which, in our case is represented by the drawn input current, the graphical representation of wavelet coefficients identifies the precise timing of discontinuities (Fig. 7).

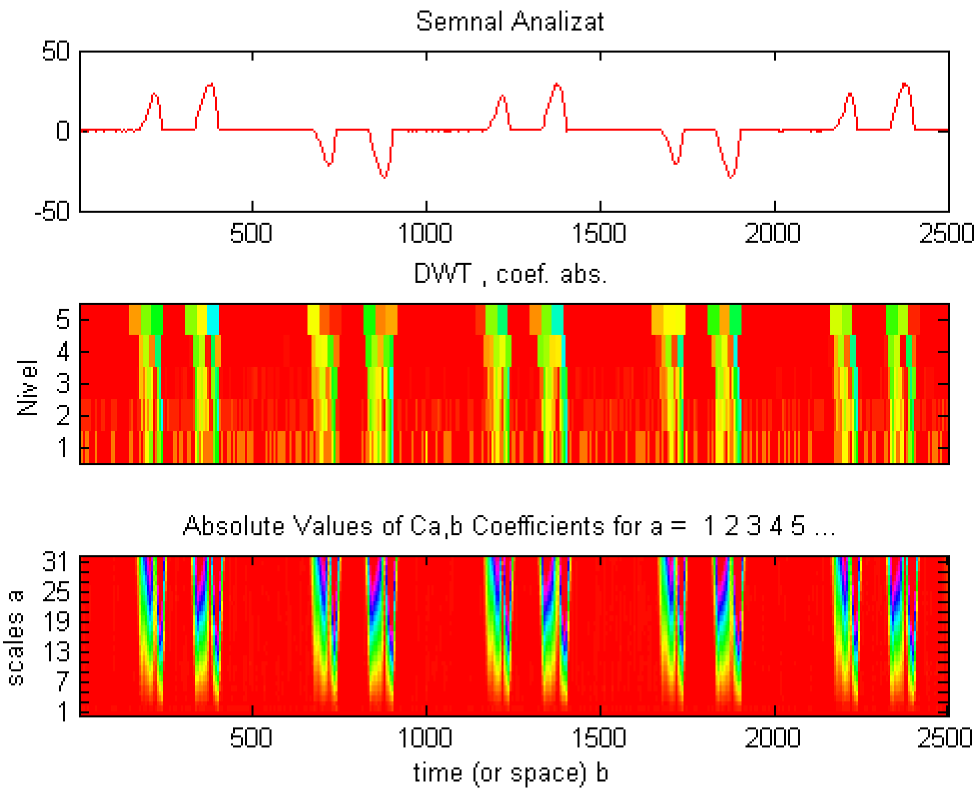

Fig. 5. Wavelet TPRD input current analysis.

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Wavelet analysis reveals details and data, which cannot be obtained by other types of analysis, such as: points of *breakdown*, points of discontinuities, etc.
In discrete wavelet transform (DWT), the original waveform S is decomposed into approximation and details. The DWT decomposition tree is as shown in figure 7a. In figure 7b, the form of the vector C is presented.

For three level DWT decomposition of the input TPRD current is shown in figure 8. We obtain the multi-resolution analysis (MRA), this meaning the decomposition of the original signal S into approximation and a number of details corresponding to transform level (Daubechies 3 in figure 8).

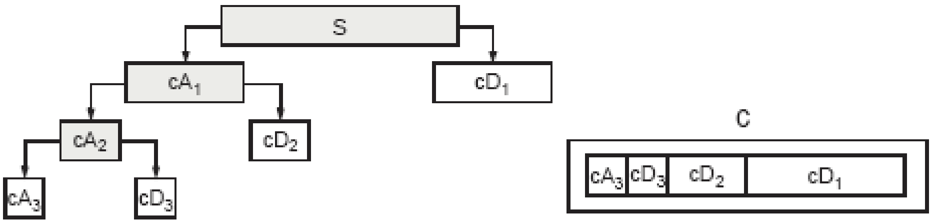

Fig. 7. a) Tree of thrid level discret wavelet (DWT) decomposition; b) C vector.

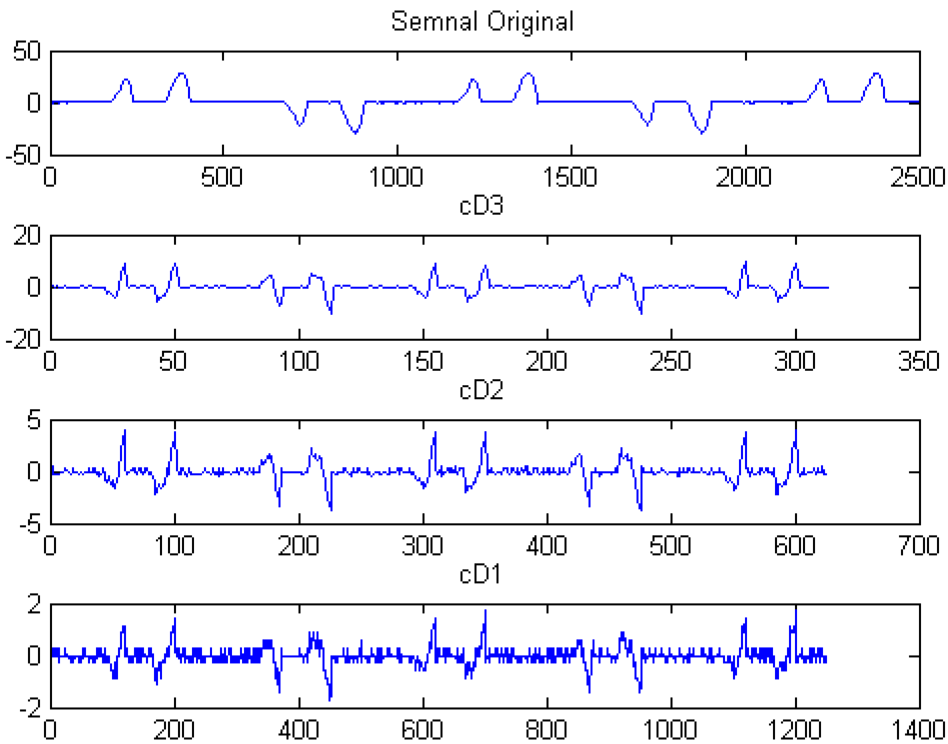

Fig. 8. The wavelet decomposition of TPRD input current:
a) cA_3 - approximation; b) cD_3 – third level details; c) cD_2 – two level details; d) cD_1 – first level details.

4. Wavelet and Fourier harmonics analysis of rectifiers with near sinusoidal input current

The topologies of rectifier with sinusoidal input current, called RNSIC1, are presented in figure 1. The load of this converter is widely variable, meeting the users needs.
Fourier analysis of input current shows ratios I_5/I_1 and I_7/I_1 smaller than 4%, and THD (2.30%), which is smaller than the international standards limits (5%).

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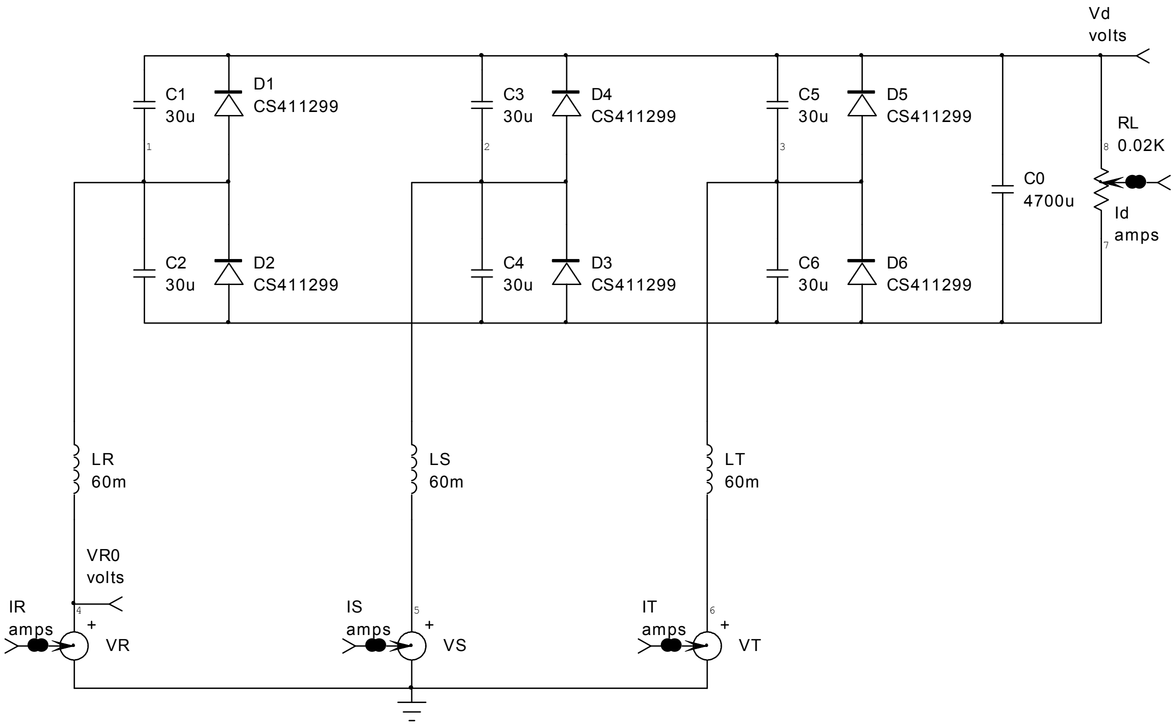

Fig. 9. The topologies of rectifier with sinusoidal input current (RNSIC).

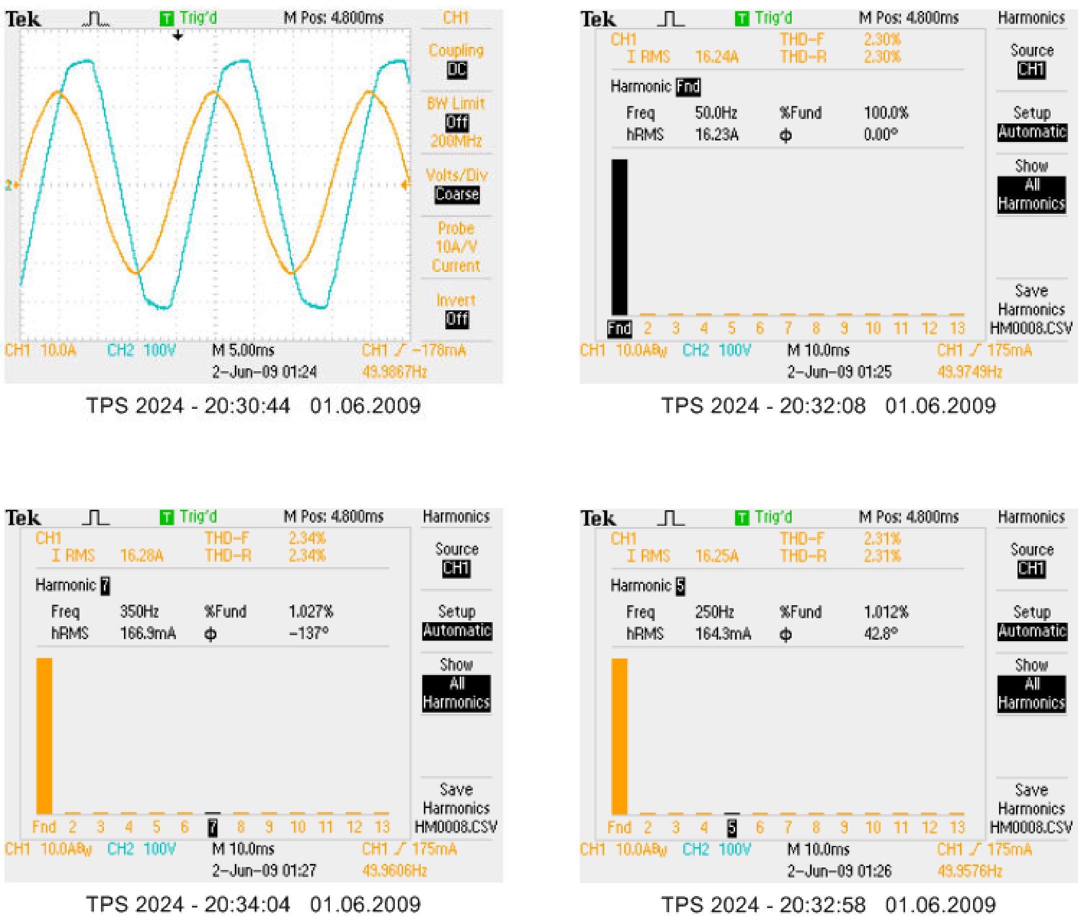

Fig. 10. a) Phase current (I_R) and phase voltage (U_R); b) Harmonics analysis of drawn phase current [32].

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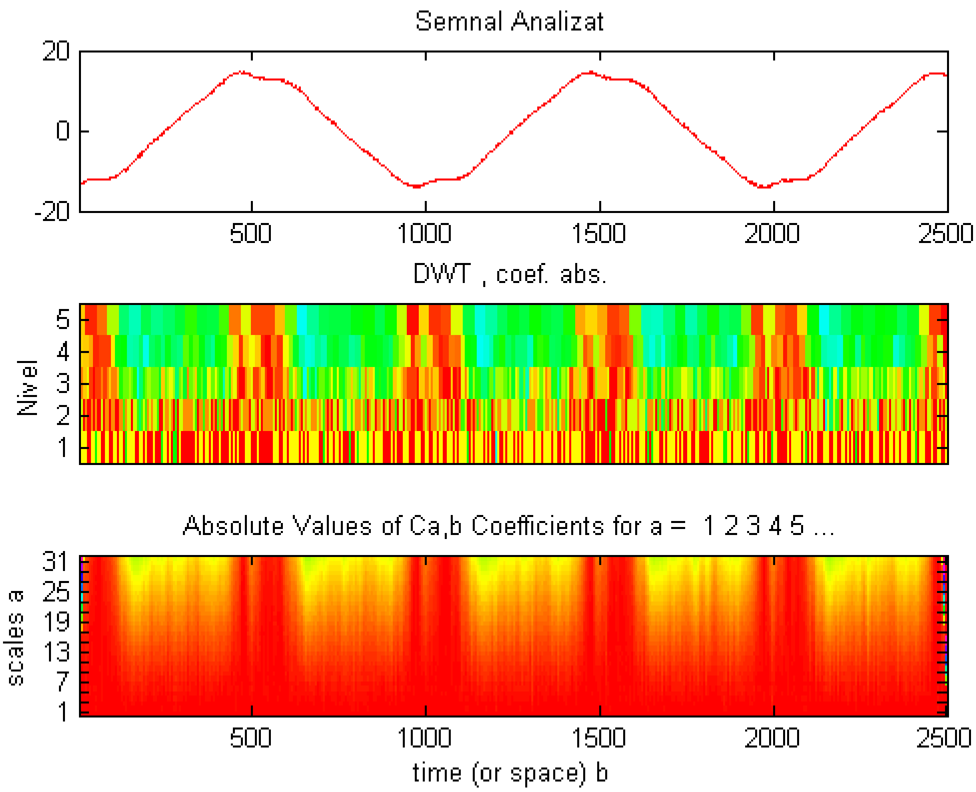

Fig. 11. The wavelet analysis of RNSIC input current.

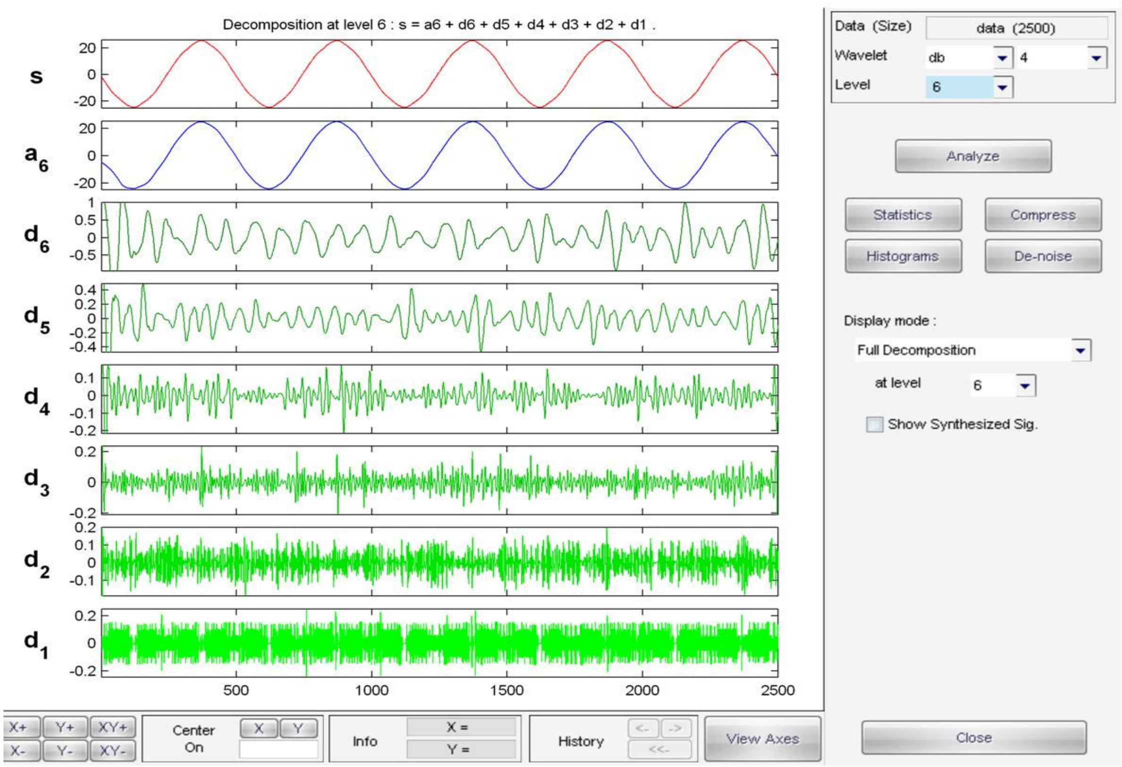

Fig. 12. The six level wavelet decomposition (Daubechies 6) of RNSIC input current:
a) s – input current (original signal); b) a_6 – six level approximation; c) d_6 – six level details; d) d_5 – five level details; e) d_4 – four level details; f) d_3 – third level details; g) d_2 – two level details; h) d_1 – first level details.

5 Conclusion

The comparative analysis of the two rectifiers, TPRD and RNSIC, highlights the fact that RNSIC represents a reliable, cost effective and efficient method for AC/DC conversion.

The ratios of harmonic currents I_5/I_1 and I_7/I_1, as well as THD, situate below the limits imposed by international standards IEEE 519/1992 and IEC 61000-3-4.

Multi-resolution analysis (MRA) with CWT and DWT confirms the distortion reduction in input current of RNSIC as compared to TPRD. In our future work, we shall try to use DWT for the calculus of current harmonics and THD. We expect the results to confirm the Fourier based calculus.

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